

CHAPTER IV - SUMMARY OF FORECAST VERIFICATION

1. ANNUAL FORECAST VERIFICATION

a. Western North Pacific Ocean

The positions given for warning times and those at the 24-, 48-, and 72-hour forecast times were verified against the post-analysis "best track" positions at the same valid times. The resultant vector and right angle (track) errors (illustrated in Figure 4-1) were then calculated for each tropical cyclone and are presented in Table 4-1. Figure 4-2 provides the frequency

distributions of vector errors in 30 nm increments for 24-, 48-, and 72-hour forecasts of all 1984 tropical cyclones in the western North Pacific. A summation of the mean vector and right angle errors, as calculated for all tropical cyclones in each year, is shown in Table 4-2. A comparison of the annual mean vector errors for all tropical cyclones as compared to those tropical cyclones that reached typhoon intensity can be seen directly in Table 4-3. The annual mean vector errors for 1984 as compared to the ten previous years are graphed in Figure 4-3.

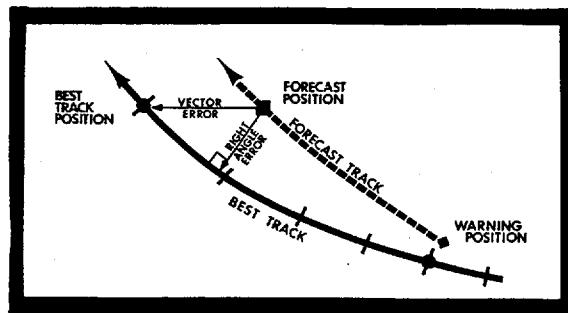


Figure 4-1. Illustration of the method to determine vector error and right angle error.

TABLE 4-1.

FORECAST ERROR SUMMARY FOR THE WESTERN NORTH PACIFIC
SIGNIFICANT TROPICAL CYCLONES OF 1984. (ERRORS IN NM)

	WARNING			24-HOUR			48-HOUR			72-HOUR		
	VECTOR ERROR	RT ANGLE ERROR	NR OF WRNGS									
01W. TS VERNON	31	28	9	116	86	5	147	55	1	389	224	16
02W. TS WYNNE	14	10	28	93	44	24	224	114	18	803	328	6
03W. TY ALEX	27	23	18	155	93	14	351	197	10	83	80	2
04W. TS BETTY	13	9	12	72	42	10	105	46	5	282	246	18
05W. TY CARY	13	7	30	92	56	26	190	149	22	564	284	23
06W. TY DINAH	20	11	35	142	73	29	336	178	25	232	117	14
07W. TY ED	12	9	28	140	82	23	328	218	8	448	283	6
08W. TS FREDA	30	20	12	163	81	9	420	296	2	311	123	16
09W. TD 09W	122	105	10	297	248	6	311	123	16	331	170	7
10W. TS GERALD	25	9	24	136	57	20	230	149	17	423	316	13
11W. TY HOLY	16	11	25	111	73	21	204	16	1	279	242	31
12W. TD 12W	46	8	5	80	63	39	179	149	35	125	85	4
13W. TY IKE	13	10	42	104	8	14	302	159	10	244	201	6
14W. TS JUNE	70	28	11	121	104	8	231	178	6	402	362	3
15W. TY KELLY	27	14	18	225	121	14	321	221	5	447	0	1
16W. TS LYNN	26	21	14	112	63	10	279	85	5	482	146	3
17W. TS MAURY	28	18	13	215	87	9	620	219	4	205	120	5
18W. TS NINA	30	12	15	156	37	9	207	179	1	498	113	1
19W. TY OGDEN	30	15	12	227	100	8	279	85	5	635	319	8
20W. TY PHYLLIS	15	12	13	113	23	9	205	128	27	353	219	23
21W. TS ROY	21	19	9	173	87	5	193	141	41	197	69	18
22W. TS SUSAN	13	9	5	47	25	1	193	161	19	406	297	39
23W. TD 23W	13	16	4	204	178	12	207	178	1	397	310	15
24W. TY THAD	19	18	21	114	86	17	286	178	12	245	165	19
25W. STY VANESSA	14	11	31	102	68	27	179	106	23	353	219	23
26W. TY WARREN	21	9	31	95	53	29	205	128	27	197	69	18
27W. TY AGNES	11	7	28	72	23	25	139	54	21	406	297	39
28W. STY BILL	20	9	52	98	50	46	226	141	41	310	286	18
29W. TY CLARA	20	13	30	94	61	26	185	93	22	265	131	18
30W. TY DOYLE	13	10	26	69	58	22	193	161	19	397	310	15
ALL FORECASTS:	22	14	611	117	66	492	233	137	378	363	231	286

TABLE 4-2.

ANNUAL MEAN FORECAST ERRORS (NM) FOR THE WESTERN NORTH PACIFIC

YEAR	24-HOUR		48-HOUR		72-HOUR	
	VECTOR	RIGHT ANGLE	VECTOR	RIGHT ANGLE	VECTOR	RIGHT ANGLE
1971	111	64	212	118	317	117
1972	117	72	245	146	381	210
1973	108	74	197	134	253	162
1974	120	78	226	157	348	245
1975	138	84	288	181	450	290
1976	117	71	230	132	338	202
1977	148	83	283	157	407	228
1978	127	75	271	179	410	297
1979	124	77	226	151	316	223
1980	126	79	243	164	389	287
1981*	123	75	220	119	334	168
1982*	113	67	237	139	341	206
1983*	117	72	259	152	405	237
1984*	117	66	233	137	363	231

* The technique for calculating right angle error was revised in 1981; therefore, a direct correlation in right angle statistics cannot be made for the errors computed before 1981 and the errors computed since 1981.

TABLE 4-3. ANNUAL MEAN FORECAST ERRORS (NM) FOR WESTERN NORTH PACIFIC

YEAR	24-HOUR		48-HOUR		72-HOUR	
	ALL	TYphoon*	ALL	TYphoon*	ALL	TYphoon*
1950-58		170				
1959		117**		267**		
1960		177**		354**		
1961		136		274		
1962		144		287		476
1963		127		246		374
1964		133		284		429
1965		151		303		418
1966		136		280		432
1967		125		276		414
1968		105		229		337
1969		111		237		349
1970	104	98	190	181	279	272
1971	111	99	212	203	317	308
1972	117	116	245	245	381	382
1973	108	102	197	193	253	245
1974	120	114	226	218	348	351
1975	138	129	288	279	450	442
1976	117	117	230	232	338	336
1977	148	140	283	266	407	390
1978	127	120	271	241	410	459
1979	124	113	226	219	316	319
1980	126	116	243	221	389	362
1981	123	117	220	215	334	342
1982	113	114	237	229	341	337
1983	117	110	259	247	405	384
1984	117	110	233	228	363	361

* for Typhoons only while winds were over 35 kt (18 m/sec).

** forecast positions north of 35°N were not verified.

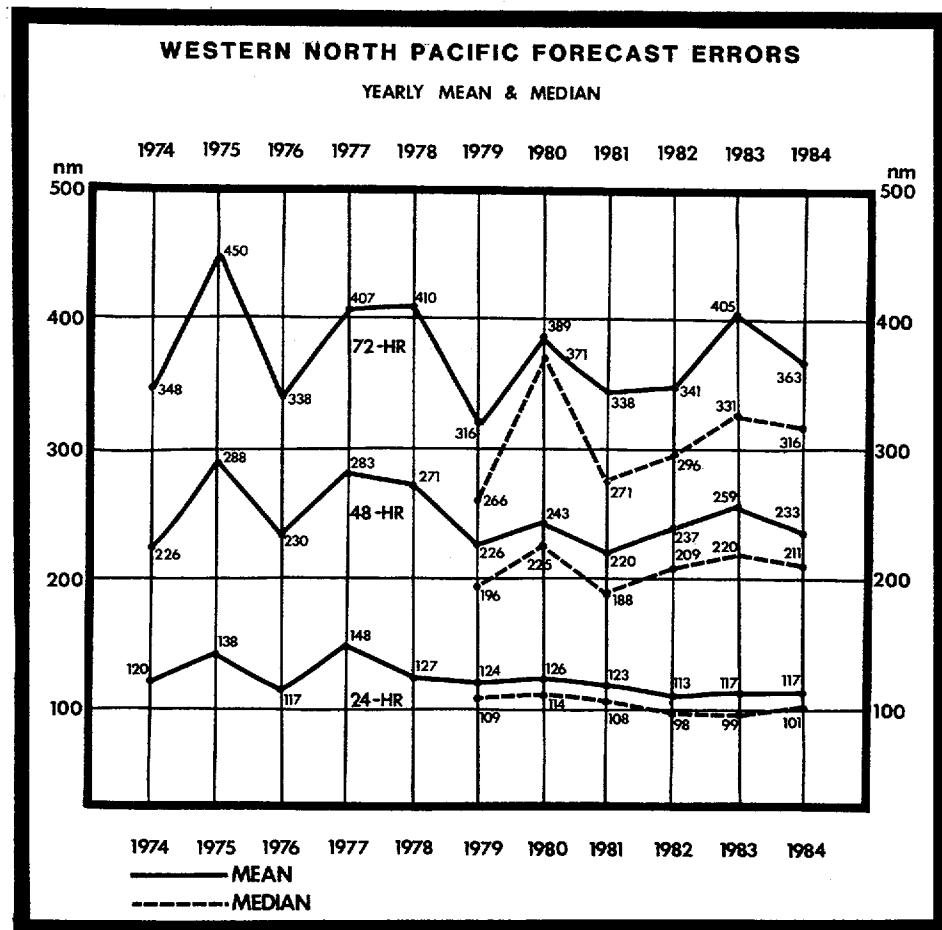


Figure 4-3. Annual mean and median vector errors (nm) for all tropical cyclones in the western North Pacific.

b. North Indian Ocean

The positions given for warning times and those at the 24-, 48-, and 72-hour valid times were verified for tropical cyclones in the North Indian Ocean by the same methods used for the western North Pacific. It should be noted that due to the low number of North Indian Ocean tropical cyclones, these error statistics should not be taken as representative of any trend.

Table 4-4 is the forecast error summary for the North Indian Ocean and Table 4-5 contains the annual average of forecast errors for each year through 1974. Vector errors are plotted in Figure 4-4. (Seventy-two hour forecast errors were evaluated for the first time in 1979). There were no verifying 72-hour forecasts in 1983.

TABLE 4-4.

FORECAST ERROR SUMMARY FOR THE NORTH INDIAN OCEAN
SIGNIFICANT TROPICAL CYCLONES FOR 1984. (ERRORS IN NM)

	TC	NAME	WARNING			24-HOUR			48-HOUR			72-HOUR		
			POSIT ERROR	RT ANGLE ERROR	NR OF WRNGS									
01.	TC	01A	31	19	9	225	79	5	347	195	1			
02.	TC	02B	29	13	8	71	40	4						
03.	TC	03B	26	16	16	132	107	9						
04.	TC	04B	38	17	34	160	60	24	271	123	19	388	159	16
ALL FORECAST:			33	16	67	154	71	42	274	127	20	388	159	16

TABLE 4-5.

ANNUAL MEAN FORECAST ERRORS FOR THE NORTH INDIAN OCEAN

YEAR	24-HOUR		48-HOUR		72-HOUR	
	VECTOR	RIGHT ANGLE	VECTOR	RIGHT ANGLE	VECTOR	RIGHT ANGLE
1971*	232	-	410	-	-	-
1972*	224	101	292	112	-	-
1973*	182	99	299	160	-	-
1974*	137	81	238	146	-	-
1975	145	99	228	144	-	-
1976	138	108	204	159	-	-
1977	122	94	292	214	-	-
1978	133	86	202	128	-	-
1979	151	99	270	202	437	371
1980	115	73	93	87	167	126
1981**	109	65	176	103	197	73
1982**	138	66	368	175	762	404
1983**	117	46	153	67	-	-
1984**	154	71	274	127	388	159

* The western Bay of Bengal and the Arabian Sea were not included in the JTWC area of responsibility until the 1975 tropical cyclone season.

** The technique for calculating right angle error was revised in 1981; therefore, a direct correlation in right angle statistics cannot be made for the errors computed before 1981 and the errors computed since 1981.

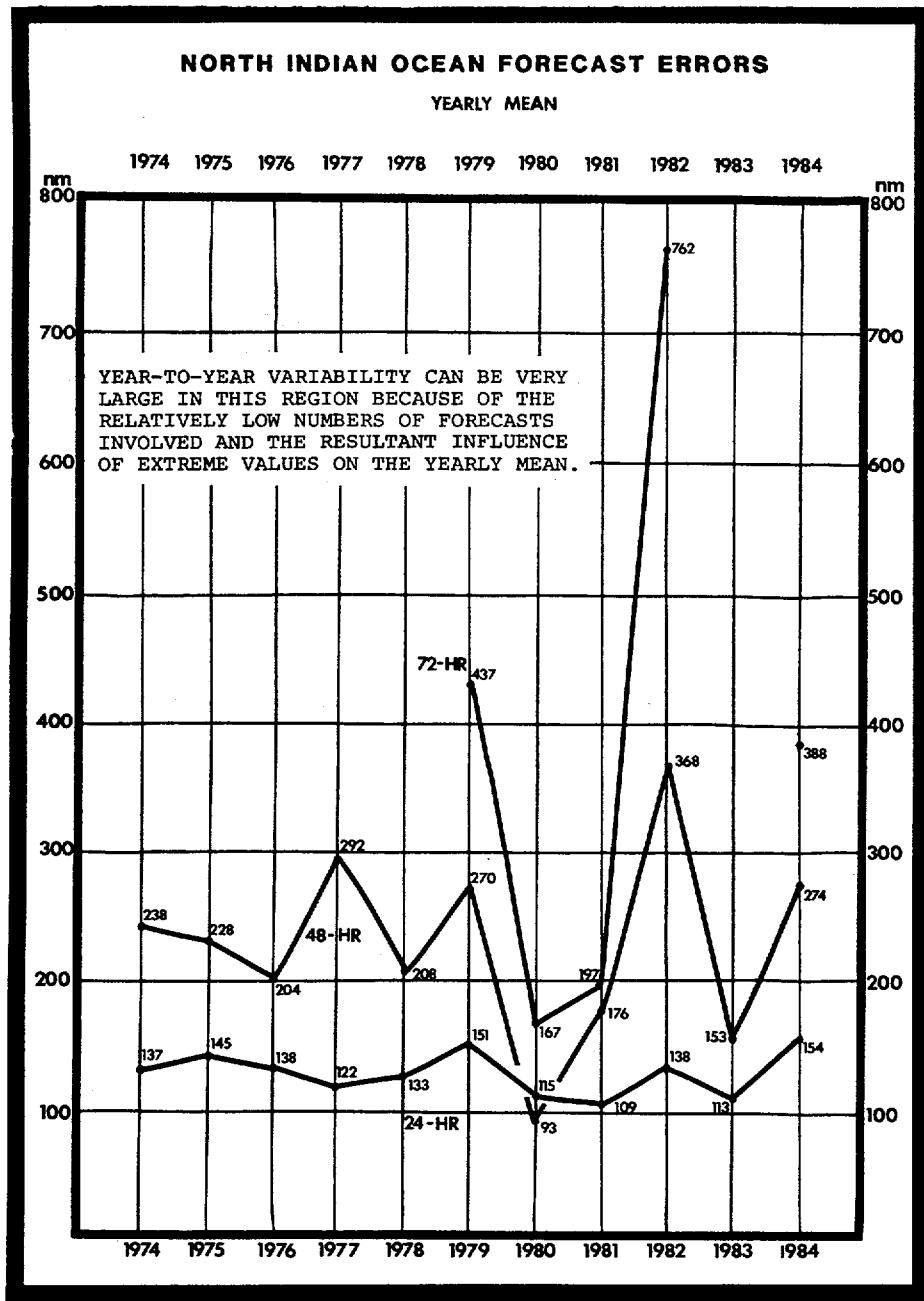


Figure 4-4. Annual mean vector errors [nm] for all tropical cyclones in the North Indian Ocean.

2. COMPARISON OF OBJECTIVE TECHNIQUES

a. General

Objective techniques used by JTWC are divided into five main categories:

- (1) extrapolation;
- (2) climatological and analog techniques
- (3) model output statistics;
- (4) dynamical models; and
- (5) empirical and analytical techniques

In September 1981, JTWC began to initialize its array of objective forecast techniques (described below) on the six-hour-old preliminary best track position (an interpolative process) rather than the forecast (partially extrapolated) warning position, e.g. the 0600Z warning is now supported by objective techniques developed from the 0000Z preliminary best track position. This operational change has yielded several advantages:

*techniques can now be requested much earlier in the warning development time line, i.e. as soon as the track can be approximated by one or more fix positions after the valid time of the previous warning;

*receipt of these techniques is virtually assured prior to development of the next warning; and

*improved (mean) forecast accuracy. This latter aspect arises because JTWC now has a more reliable approximation of the short-term tropical cyclone movement. Further, since most of the objective techniques are biased for persistence, this new procedure optimizes their performance and provides more consistent guidance on short-term movement, indirectly yielding a more accurate initial position estimate as well as lowering 24-hour forecast errors.

b. Description of Objective Techniques

(1) XTRP -- Forecast positions for 24- and 48-hours are derived from the extension of a straight line which connects the most-recent and 12-hour-old preliminary best track positions.

(2) CLIM -- A climatological aid providing 24-, 48-, and 72-hour tropical cyclone forecast positions (and intensity changes in the western North Pacific) based upon the position of the tropical cyclone. The output is based upon data records from 1945 to 1981 for the western North Pacific Ocean and 1900 to 1981 for the North Indian Ocean.

(3) TPAC -- Forecast positions are generated from a blend of climatology and persistence. The 24- and 48-hour positions are equally weighted between climatology and persistence and the 72-hour position is one quarter persistence and three quarters climatology. Persistence is a straight line extension of a line connecting the current and 12-hour-old positions. Climatology is based on data from 1945 to 1981 for the western North

Pacific Ocean and 1900 to 1981 for the North Indian Ocean.

(4) TYAN78 -- An updated analog program which combines the earlier versions TYFN 75 and INJAN 74. The program scans a 30-year climatology with a similar history (within a specified acceptance envelope) to the current tropical cyclone. For the western North Pacific Ocean, three forecasts of position and intensity are provided for 24-, 48-, and 72-hours: RECR - a weighted mean of all accepted tropical cyclones which were categorized as "recurving" during their best track period; STRA - a weighted mean of all accepted tropical cyclones which were categorized as moving "straight" (westward) during their best track period; and TOTL - a weighted mean of all accepted tropical cyclones, including those used in the RECR and STRA forecasts. For the North Indian Ocean, a single (total) forecast track is provided for 12-hour intervals to 72 hours.

(5) COSMOS -- A model output statistics (MOS) routine based on the geostrophic steering at the 850-, 700-, and 500-mb levels. The steering is derived from the HATTRACK point advection model run on Global prognostic fields from the FLENUMOCEANCEN NOGAPS prediction system. The MOS forecast is then blended with the 6-hour past movement to generate the forecast track.

(6) OTCM -- (One-way Interactive Tropical Cyclone Model) A coarse-mesh, three-layer in the vertical, primitive equation model with a 205 km grid spacing over a 6400 X 4700 km domain. The model's fields are computed around a bogus, digitized cyclone vortex using FLENUMOCEANCEN Numerical Variational Analysis (NVA) or NOGAPS prognostic fields for the specified valid time. The past motion of the tropical cyclone is compared to initial steering fields and a bias correction is computed and applied to the model. FLENUMOCEANCEN NOGAPS global prognostic fields are used at 12-hour intervals to update the model's boundaries. The resultant forecast positions are derived by locating the 850 mb vortex at six hour intervals to 72-hours.

(7) NTCM -- (Nested Tropical Cyclone Model) A primitive equation model with similar properties as the OTCM. The NTCM differs by containing a finer scale "nested" grid, initializing on NVA analysis fields only, not containing a (persistence) bias correction, and being a channel model which runs independent of FLENUMOCEANCEN prognostic fields (not requiring updating of its boundaries). The "nested grid" covers a 1200 X 1200 km area with a 41 km grid spacing which moves within the coarse-mesh domain to keep an 850 mb vortex at its center.

(8) TAPT -- An empirical technique which utilizes upper-tropospheric wind fields to estimate acceleration associated with the tropical cyclones interaction with the mid-latitude westerlies. It includes guidelines for duration of acceleration, upper-limits, and probable path of the cyclone.

(9) CLIP -- A statistical regression technique based on climatology, current intensity and position and past movement. This technique is used as a crude measure of real forecast skill when verifying forecast accuracy.

(10) THETA E -- An empirically derived relationship between a tropical cyclone's minimum sea-level pressure (MSLP) and 700 mb equivalent potential temperature (θ_e) was developed by Sikora (1976) and Dunnavan (1981). By monitoring MSLP and θ_e trends, the forecaster can evaluate the potential for sudden, rapid deepening of a tropical cyclone.

(11) WIND RADIUS -- Following an analytic model of the radial profiles of sea-level pressures and winds in mature tropical cyclones (Holland, 1980), a set of radii for 30-, 50-, and 100-knot winds based on the tropical cyclone's maximum winds have been produced to aid the forecaster in determining forecast wind radii.

(12) Dvorak -- An estimation of a tropical cyclone's current and 24-hour forecast intensity is made from interpolation of satellite imagery (Dvorak, 1973, 1982) and provided to the forecaster. These intensity estimates are used in conjunction with other intensity-related data and trends to forecast

tropical cyclone intensity.

JTWC currently uses TPAC, TAPT, TYAN78, COSMOS, and OTCM operationally with NTCM in an evaluation mode to develop track forecasts.

c. Testing and Results

A comparison of mean and median forecast errors (for a non-homogeneous data set) is provided for selected techniques in Table 4-6 for all western North Pacific tropical cyclones and in Table 4-8 for all North Indian Ocean tropical cyclones.

A comparison of selected techniques is included in Table 4-7 for all western North Pacific tropical cyclones and in Table 4-9 for all North Indian Ocean tropical cyclones. In these tables, "X-Axis" refers to techniques listed vertically. The example in Table 4-7 compares COSM to OTCM, i.e. in the 461 cases available for a (homogeneous) comparison, the average vector error at 24 hours was 125 nm for COSMOS and 129 nm for OTCM. The difference of 4 nm is shown in the lower right. (Differences are not always exact, due to computational round-off which occurs for each of the cases available for comparison).

TABLE 4-7. 1984 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE WESTERN NORTH PACIFIC OCEAN
24-HOUR FORECAST ERRORS (NM)

	JTWC	RECR	CLIP	TOTL	COSM	NTCM	OTCM	TPAC	CLIM	XTRP	HPAC
JTWC	492	117									
	117	0									
RECR	459	115	472	130							
	128	13	130	0							
CLIP	409	117	392	130	422	120					
	119	2	117	-12	120	0					
TOTL	475	115	471	130	409	117	489	130			
	129	14	129	0	130	13	130	0			
COSM	473	117	456	129	408	119	473	130	486	125	
	122	6	123	-6	127	7	122	-6	125	0	
NTCM	421	117	404	130	421	120	421	130	420	126	435
	120	3	119	-10	122	1	118	-11	120	-5	121
OTCM	461	116	442	128	401	120	459	129	461	125	413
	128	12	129	0	132	12	128	0	129	4	121
TPAC	484	116	466	129	416	120	482	129	479	124	428
	132	15	131	2	133	13	131	2	133	9	132
CLIM	488	116	470	129	420	120	466	129	483	125	432
	180	64	181	52	183	63	181	52	183	58	182
XTRP	487	117	468	129	419	120	485	130	482	124	431
	124	7	123	-6	126	5	123	-5	126	1	126
HPAC	485	116	467	129	417	120	483	129	480	124	429
	132	15	131	2	133	13	131	2	133	9	132

48-HOUR FORECAST ERRORS (NM)

	JTWC	RECR	CLIP	TOTL	COSM	NTCM	OTCM	TPAC	CLIM	XTRP	HPAC
JTWC	378	233									
	233	0									
RECR	358	231	376	285							
	277	46	285	0							
CLIP	322	232	323	280	344	262					
	255	23	258	-21	262	0					
TOTL	366	230	374	285	325	257	389	288			
	283	53	284	0	282	26	288	0			
COSM	364	231	363	283	333	261	376	288	387	246	
	237	6	246	-36	248	-12	242	-45	246	0	
NTCM	331	231	332	280	343	262	344	283	342	246	353
	252	21	255	-24	258	-2	251	-30	255	9	257
OTCM	344	231	342	277	314	259	353	284	355	243	321
	241	9	239	-37	245	-13	238	-44	239	-2	246
TPAC	372	230	371	283	340	260	383	285	381	246	349
	277	47	281	-1	282	21	280	-4	284	38	281
CLIM	375	231	374	284	343	261	386	286	384	246	352
	353	122	358	74	360	99	360	74	363	117	359
XTRP	374	232	372	284	341	261	385	288	383	246	350
	281	49	286	2	293	32	286	0	292	46	291
HPAC	372	230	371	284	340	261	383	286	381	246	349
	278	47	282	-1	283	22	281	-4	285	39	281

JTWC - OFFICIAL JTWC FORECAST
RECR - RECURVER (TYAN 78)
CLIP - CLIPPER
TOTL - TOTAL (TYAN 78)
COSM - COSMOS (MOS)
NTCM - NESTED TROPICAL CYCLONE MODEL
OTCM - ONE-WAY TROPICAL CYCLONE MODEL
TPAC - CLIM AND PERSISTENCE BLEND
CLIM - CLIMATOLOGY
XTRP - 12-HOUR EXTRAPOLATION
HPAC - MEAN OF XTRP AND CLIM

72-HOUR FORECAST ERRORS (NM)

	JTWC	RECR	CLIP	TOTL	COSM	NTCM	OTCM	TPAC	CLIM
JTWC	286	363							
	363	0							
RECR	272	371	289	477					
	474	103	477	0					
CLIP	251	365	254	473	267	413			
	404	39	418	-54	413	0			
TOTL	278	366	288	477	261	414	296	470	
	464	98	474	-3	464	50	470	0	
COSM	277	358	280	473	259	411	287	467	295
	386	28	397	-74	387	-22	393	-72	389
NTCM	259	365	262	471	266	414	269	465	267
	432	67	435	-35	432	18	433	-32	422
OTCM	235	366	244	492	219	426	246	472	244
	364	-1	364	-127	359	-66	364	-106	358
TPAC	282	360	284	476	264	413	291	468	290
	450	90	457	-17	499	37	453	-14	451
CLIM	285	361	287	476	267	413	294	470	293
	513	152	515	39	508	95	512	42	511

TABLE 4-9. 1984 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN

48-HOUR FORECAST ERRORS (NM)											
JTWC	TOTAL	NTCM	OTCM	TPAC	CLIM	XTRP	HPAC				
JTWC	20 274										
	274 0										
TOTAL	14 303	292 11	26 299	299 0							
NTCM	19 283	271 13	24 345	303 42	33 322	322 0					
OTCM	18 289	263 27	24 364	293 71	31 312	317 -4	33 318	318 0			
TPAC	19 359	285 73	26 307	299 8	32 310	325 -15	32 301	325 -23	34 308	308 0	
CLIM	19 466	285 181	26 379	299 80	32 384	325 59	32 372	325 47	34 387	308 79	34 387
XTRP	20 272	274 -1	26 259	299 -39	33 287	322 -33	33 285	318 -31	34 285	308 -22	34 285
HPAC	19 358	285 73	26 307	299 8	32 309	325 -15	32 301	325 -23	34 308	308 0	34 -78

JTWC - OFFICIAL JTWC FORECAST
 TOTAL - ANALOG (TYAN 78)
 NTCM - NESTED TROPICAL CYCLONE MODEL
 OTCM - ONE-WAY TROPICAL CYCLONE MODEL
 TPAC - CLIM AND PERSISTENCE BLEND
 CLIM - CLIMATOLOGY
 XTRP - 12-HOUR EXTRAPOLATION
 HPAC - MEAN OF XTRP AND CLIM

72-HOUR FORECAST ERRORS (NM)											
JIWC		TOTAL		NTCM		OTCM		TPAC		CLIM	
JIWC	16	388									
	388	0									
TOTAL	12	368	22	476							
	475	107	476	0							
NTCM	15	383	21	475	25	547					
	417	34	567	92	547	0					
OTCM	6	489	11	542	11	669	12	290			
	290	-198	304	-237	286	-382	290	0			
TPAC	16	388	22	476	25	547	12	290	26	566	
	616	229	545	69	553	5	669	379	566	0	
CLIM	16	388	22	476	25	547	12	290	26	566	26
	691	303	616	140	609	61	788	498	629	64	629